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The Implementation of a Provision Against Progressive Collapse

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AGAINST PROGRESSIVE COLLAPSE

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by

Felix Y. Yokel, James H. Pielert
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The design solutions used by five U.S. precast concrete housing
systems to comply with a provision against progressive collapse
are studied and compared. Some common characteristics of the
design solutions are identified.

1. Introduction

In 1969 the Department of Housing and Urban Development (HUD) initiated Operation Breakthrough, a program designed to encourage the development and introduction of industrialization into the housing industry in the United States. Under the Breakthrough program a number of housing systems were selected, evaluated, and constructed on demonstration sites. The National Bureau of Standards, on behalf of HUD, drafted criteria [1][1] which were used to guide the development and subsequent evaluation of these housing systems. These "Guide Criteria" contained a provision against progressive collapse under catastrophic loading which was not previously contained in any U.S. code or standard (Progressive collapse may be defined as a chain reaction of failures following damage to only a relatively small portion of a structure). This report discusses the implementation of this provision.

2. The Criterion and its Interpretation

The criterion against progressive collapse used in Operation Breakthrough is quoted below:

o Requirement

Explosions or other catastrophic loads on any one story level should not cause progressive structural collapse at other levels.

o Criterion:

The criterion applies to buildings four stories or higher. At a load level of one dead + 0.5 live, the accidental removal of any one of the following (load) supporting structural elements at one level should not cause collapse of the structure on another level:

a. two adjacent wall panels forming an exterior corner
b. one wall panel in a location other than an exterior corner
c. one column or other element of the primary structural support system.

This criterion is waived if the above-mentioned structural element or elements are capable of resisting a pressure of 5 psi (34.5 kPa), applied in the most critical manner within one story level to one face of the element and of all space dividers supported by the element or attached to it.

o Test:

Analysis and/or physical simulation

o Commentary:

The need for this requirement is emphasized by several recent catastrophes. The collapse of the Ronan Point Apartment Building, London, demonstrated one source of catastrophic loading, namely a gas explosion. The Tribunal investigating the cause of this collapse [2] pointed out that "the problem of progressive collapse had not been considered by most structural engineers concerned with the development of tall system-built blocks". Systems meeting this requirement would be designed to withstand local explosion. This criterion is conservative and was tentatively adopted in accordance with the tribunal's recommendations.

The word "panel" is used to describe a portion of an interior or exterior bearing wall between two primary structural members, or between two interior walls, or between a corner and either an interior wall or a primary structural member.

This criterion was written with gas explosions in mind, but it was also envisioned that other abnormal loads (loads not normally considered by designers) may occur and cause the failure of a primary structural member. The progression of collapse considered in this criterion is in a vertical direction. There are no explicit limitations on the horizontal spread of

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[1]Figures in brackets indicate literature references.

progressive collapse within a single story. The load considered is 50 percent of the design live load, accounting for the low probability of the coincidence of a catastrophic load with full design live load. The criterion does not require consideration of the debris loading that the collapse of part of the structure could generate. The criterion provides the option of either designing "strong" members, capable of resisting the 5 psi (34.5 kPa) pressure, or providing an "alternate path" of load support.

In the implementation of the criterion the assumption was made that a wall panel can only be considered "strong" if the panel itself, as well as the lateral supports necessary to insure its stability under the stipulated minimum load of dead plus 0.5 live, would survive after the 5 psi (34.5 kPa) pressure is applied.

It is not the intent of this report to discuss the need for, or the adequacy of, the quoted criterion. Since the time the criterion was proposed, the matter of progressive collapse has been under consideration by professional committees in the U.S., however, no formal recommendations have been adopted by the profession.

3.   Case Histories

3.1   General

Selected case histories of Operation Breakthrough systems are described in order to illustrate specific approaches which were judged by designers to satisfy the stated criterion. It is realized that the design solutions described do not necessarily represent the only way in which the criteria could have been satisfied. However the case histories illustrate some of the approaches that other designers might consider when faced with the task of increasing the resistance of buildings to progressive collapse.

The general features of these systems were previously described elsewhere [3], although specific features relating to progressive collapse have not been discussed to the extent presented below.

3.2   The FCE-Dillon System

This system was developed in the U.S. and adapted to meet the Breakthrough requirements. A typical portion of a floor plan is shown in figure 1. The structural components, as numbered in figure 1, are: precast, hollow-core bearing walls (1) typically 28 ft x 8 ft-7 1/2 in x 8 in (8.53 m x 2.63 m x 20.3 cm); precast prestressed floor planks (2), typically 32 ft x 8 ft x 6 in (9.75 m x 2.44 m x 15.2 cm) and 22 ft-4 in x 8 ft x 4 in (6.81 m x 2.44 m x 10.1 cm); 8 in (20.3 cm) thick balcony and stairwell floor panels (3), preassembled kitchen and utility (heart) modules (4) resting on 8 in (20.3 cm) thick floor panels of typical floor-plank dimensions, "double T" exterior walls at the end of the stairwells (5), 43 ft-7 in high x 7 ft-7 in wide (13.28 m x 2.31 m); and elevator-shaft units not shown in the portion of the floor plan in figure 1. Clear spans between bearing walls are 22 ft (6.71 m) and 31 ft-8 in (9.65 m).

A typical hollow-core bearing wall section and floor to wall joint detail are shown in figure 2. After erection and appropriate shoring, vertical reinforcement is inserted in some of the hollow cores, and horizontal reinforcement is placed on top of the floor planks. Subsequently, the reinforced wall cores are filled with concrete and a cast in place concrete topping is placed on the floor planks to a total floor thickness of 8 in (20.3 cm). The horizontal and vertical reinforcement is continuous through interior joints, and horizontal bars are anchored in the exterior wall joints to develop their full tensile strength. There are reinforcement ties between the floor slabs of the heart modules and adjacent slabs.

All bearing walls are designed as "strong" members and thus are capable of resisting the stipulated 5 psi (34.5 kPa) pressure. This approach is not difficult to implement since the unsupported (floor to ceiling) height is only 8 ft (2.44 m). However, the floor planels have a much larger unsupported span and can not be economically designed to resist an upward or downward pressure of 5 psi (34.5 kPa). In the case of a space enclosed by two interior

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bearing walls even floor panels on two consecutive levels between these walls could fail without depriving the walls of their lateral support, which in this case would be provided by floor panels on the other side of the walls. A problem, however, arises when one or both of the bearing walls are exterior walls, since the loss of a floor panel would deprive these walls of lateral support, causing a stability failure. This problem is solved by providing specially-strengthened partitions. A typical detail of such a partition is shown in figure 3. The effect of the partition is illustrated in figure 4. While the partition in the space within which the 5 psi (34.5 kPa) pressure is applied is not expected to survive, the partitions in the stories above and below this space provide reaction forces, thus reducing the effective span of the floor and ceiling panels. The reaction force transfered to the partition is resisted by one or two successive floor (ceiling) panels or transfered directly to the foundation. If the 5 psi (34.5 kPa) pressure is applied in the space below the roof, the roof panel would fail. However, a roof panel failure would not trigger a progressive collapse. Since the specially-designed partitions are located where partitions are required in any case, the cost increase does not exceed the difference in cost between the special partitions and the non-loadbearing drywall partitions used in other parts of the housing unit.

3.3 The Descon Concordia System

The Descon Concordia System is a large-panel concrete system that was developed in Canada. The structural components of the system are shown in figure 5, and consist of: precast concrete wall panels (1), typically 30 ft x 8 ft x 6 1/2 in (9.14 m x 2.44 m x 16.5 cm) with 1 1/2 in (3.8 cm) insulation and a 3 in (7.6 cm) thick concrete cladding panel added for exterior walls; precast prestressed floor panels (2), typically 22 ft x 10 ft x 6 1/2 in (6.71 m x 3.05 m x 16.5 cm); two panelized longitudinal shear walls not shown in figure 5, located on opposite sides of the corridor, 18 ft-1 in (5.51 m) long and 10 in (25.4 cm) thick; and non-loadbearing window panels (3). Clear floor spans between transverse bearing walls are 21 ft-5 in (6.53 m).

All panels are connected by bolted connections which are located as shown in figure 5 (A & B) Typical bolted connections are shown in figure 6. All connections are capable of transmitting tensile and shear forces.

As in the case of the Dillon System, all bearing walls are designed as "strong" walls. Again, loss of the floor and ceiling in an interior unit would not cause collapse of the bearing walls which would receive lateral support from floor panels on the other side. However, an exterior bearing wall could collapse after losing the lateral support from a floor. Thus special "strong" floor panels were provided. The location of these panels is shown in figure 5. Instead of strengthening an entire panel, each of the strong panels was provided with two heavily-reinforced bands, as shown in figure 7. These bands were designed to survive the 5 psi (34.5 kPa) pressure while the rest of the panels would break away at a lower pressure. After an explosion these strong bands together with other remaining panels, such as balcony and corridor floor panels, would provide lateral support to the exterior wall.

3.4 The Rouse-Wates System

This system is an adaptation of the European Wates system. Figure 8 is a portion of a typical floor plan. The structural elements are: "strong" bearing wall panels (1); interior bearing wall panels (2); nonbearing exterior wall panels (3); corridor wall panels (4); regular floor panels (5); "strong" floor panels (6); and corridor floor panels (7). Typical panel sizes for the floor plan in figure 8 are 19 ft-9 in x 7 ft-5 in x 8 in (6.02 m x 2.26 m x 20.3 cm) for floor panels, and 22 ft x 8 ft x 7 in (6.71 m x 2.44 m x 17.8 cm) for bearing wall panels. Clear floor spans between transverse bearing walls are 19 ft-5 in (5.92 m).

Figure 9 shows a typical cast in place horizontal joint at an interior bearing wall panel. The joint provides reinforcement ties between adjacent floor elements and between floor elements and their supporting bearing walls. There are no vertical ties between successive bearing-wall panels. Vertical joints are unreinforced.

Compliance with the criterion, as documented by the designers, is by a combination of "strong" bearing walls and alternate paths of load support. As shown in figure 8, two parallel strong bearing walls (1) enclose the spaces next to the exterior walls. As in the previously-discussed cases, strong floor panels (6) must also be provided to insure lateral support for the strong exterior walls. The interior walls and floors are not designed to resist 5 psi (34.5 kPa). If any interior bearing wall is removed, the floor supported by this wall will fail, and the wall above the floor is designed to act as a cantilever girder connected to the corridor wall. The longitudinal reinforcement in the joint in figure 9 is anchored so that tensile forces at the top of the suspended wall can be transmitted to the corridor slab. According to the designers, the cantilever moment would be resisted by the corridor slabs at the top and bottom of the suspended wall. The vertical joint between the suspended wall and the corridor wall would resist the cantilever shear.

The Rouse-Wates system was also designed to meet the following prescriptive provisions of Addendum No. 1 (1970) to the British Standard Code of Practice CP116 [3]:

1. horizontal wall to floor joints capable of resisting 1700 lb per ft (2.48 kN/m) at the bottom of the wall,

2. an uninterrupted peripheral tie at each floor level to resist a force of 9000 lb (40.03 kN),

3. internal ties, anchored to the peripheral tie, capable of resisting a force of 1700 lb per foot (2.48 kN/m) in the longitudinal direction and 850 lb per foot (1.24 kN/m) acting over half a bay width in the transverse direction (the bars in the transverse direction were concentrated in the horizontal joints between transverse bearing walls).

3.5 The Camci System

This system is an adaptation of the European Tracoba System. Figure 10 shows a portion of a typical floor plan. Typical connection detail is shown in figure 11. The main structural components are: transverse exterior wall panels (1), 11 in (27.9 cm) thick, including an insulating layer between a 6-in (15.2 cm) thick interior concrete panel and a 3 in (7.6 cm) thick exterior concrete panel; transverse interior wall panels (2), typically 24 ft-10 in x 8 ft x 6 in (7.57 m x 2.44 m x 15.2 cm); 6 in (15.2 cm) thick longitudinal corridor wall panels (3); 10 in (25.4 cm) thick facade (window wall) panels (4); floor panels (5), typically 25 ft-1 in x 12 ft-1 in x 5 1/2 in (7.65 m x 3.68 m x 14.0 cm); roof parapets, not shown in figure 10, 10 in (25.4 cm) or 11 in (27.9 cm) thick and extending 7 ft-3 in (2.21 m) above the roof level; and externally-attached balcony units (6). Clear floor spans between transverse bearing walls range from 10 ft (3.05 m) to 12 ft (3.66 m).

It can be seen from figure 11 that continuous reinforcement (anchored hairpin reinforcement) extends through all the horizontal and vertical cast-in-place joints. There are also mechanical connectors providing vertical continuity between all the transverse walls, and between all roof parapets and their supporting walls.

Compliance with the progressive collapse criterion is entirely by alternate paths of load support. Thus removal of any one bearing wall panel or any two adjacent wall panels at an exterior corner should not cause progressive collapse. The most critical case is illustrated by figure 12 and occurs in the story below the top story. One gable wall and one facade wall are removed. It is assumed that floor EFGH is left in place and has to support 1/2 the live load. The slab is supported by bearing walls along sides EF and GF. Side EH is suspended from panel ADHE by the reinforced joint (see figure 11). Wall panels ADHE and DCGH are connected to parapet panels LKDA and KJID by vertical connectors and by continuous vertical reinforcement in joint HDK, which also connects the two wall panels to each other. The suspended wall panels are also connected to adjacent panels through vertical joints GC and EA. Panel ADHE, as well as panel DCGH together with parapet KJID, act as

cantilever girders. Shear is resisted by the vertical joints and by parapet panel KJID, and the floor and roof slabs at joints EF, AB, GF and CB assist in resisting the moments by providing moment-resisting couples. Similar less critical alternate paths of load support can be shown to exist when bearing wall panels at lower levels are removed.

3.6   The BSI System

This system is an adaptation of the European Balency-Schuhl system. A portion of a typical floor plan is shown in figure 13. Figure 14 shows typical joint detail.

The main structural components are: exterior wall panels (1), 7 1/2 in (19.1 cm) thick; interior wall panels (2) including corridor walls, with a maximum size of 21 ft x 8 ft x 6 in (6.40 m x 2.44 m x 15.2 cm); "strong" interior wall panels (3), 6 in (15.2 cm) thick; and floor panels (4) with a maximum size of 21 ft-6 in x 12 ft-2 in x 6 in (6.55 m x 3.71 m x 15.2 cm). Clear floor spans between transverse bearing walls range from 11 ft (3.35 m) to 12 ft (3.66 m).

The vertical joints shown in figure 14 provide continuous (interlocking) reinforcement in the horizontal, as well as the vertical direction. Horizontal joints provide ties between adjacent floor elements and between floor elements and the top of supporting bearing walls. Vertical ties between successive bearing walls are only provided in the end walls.

Compliance with the progressive collapse criterion is generally by alternate paths of load support, except for some isolated interior wall panels which were designed as strong panels. The alternate paths are made possible by the continuity of the vertical joints. For example, if panel F110 in figure 13 is removed, the panel above will be supported by panels F113 and F100, a panel enclosing an exterior balcony. The continuous vertical joints would also permit cantilever support of larger portions of the building in a manner similar to that discussed for the Camci system. On the other hand, panel R101 which does not have this type of support from vertical joints, was designed as a "strong" panel.

4.   Some Common Characteristics of the Design Solutions

The systems described in Section 3 can be categorized as long-span systems and short-span systems. The long-span systems include FCE-Dillon, Descon Concordia and Rouse-Wates. Their clear floor spans between bearing walls range from 19 ft-5 in (5.92 m) to 31 ft-8 in (9.65 m) and the spaces between transverse bearing walls are sub-divided by non-loadbearing partitions. The short-span systems are Camci and BSI, with floor spans ranging from 10 ft (3.05 m) to 12 ft (3.66 m).

All long-span systems relied on "strong" bearing walls to comply with the progressive collapse criterion. The "strong" bearing walls always include the end walls and the cross walls following the end walls. The systems have the common problem of providing lateral support to the end walls. This problem was solved by the three systems in three different ways: FCE Dillon used specially designed partitions to provide intermediate support to the floors; Descon-Concordia used floor panels with strong bands; and Rouse-Wates used strong floor panels.

No specific common joint-reinforcement requirements can be identified for the long-span systems using strong bearing walls, except those arising from the requirement that connections between strong members must resist the reaction forces caused by the specified design pressure of 5 psi (34.5 kPa). In the case of the Rouse-Wates system, where an alternate path of load support was intended for interior cross-wall panels, the designers used continuous horizontal reinforcement between the floor slabs resting on the transverse bearing walls and the corridor floor slab, between the floor slabs resting on both sides of a transverse bearing wall, and between the transverse bearing walls and the floor slabs above. The designers also relied on longitudinal reinforcement on top of transverse bearing walls, and particularly, on anchorage of this reinforcement into the corridor slab.

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The short-span systems relied primarily on alternate paths of load support. The Camci system relied on a roof parapet to support the uppermost story. The following joint reinforcement was needed in both systems to comply with the progressive collapse criterion: (1) the vertical joints between adjacent and intersecting wall panels were the most critical. These had to be reinforced horizontally to transmit horizontal tensile forces between adjacent wall panels, and vertically to resist tensile forces between successive stories; (2) the horizontal joints between the corridor floor slabs and slabs on the other side of the corridor walls were also critical. Reinforcement ties between the corridor floor slabs and the adjacent floor slabs and between the corridor and transverse walls and the corridor floor slabs insured that the corridor slabs could be engaged in resisting moments transmitted by cantilevering transverse bearing walls; (3) the horizontal joints between transverse bearing walls and floor panels resting on both sides of these walls were somewhat less critical, but in all cases reinforcement similar to that in the horizontal joints at the corridor floor slabs was needed; (4) vertical reinforcement ties between successive bearing walls panels, in addition to those provided by the continuous vertical reinforcement bars within the vertical joints, were only necessary in the upper story of the Camci system where the roof parapet was engaged to support the uppermost story. However it can be shown that such reinforcement would substantially increase the load resistance of suspended bearing walls in stories below the top story.

5. Conclusions

The following conclusions are drawn from the study of the design solutions discussed in this report.

1. The systems with clear spans between transverse bearing walls greater than 19 ft (5.79 m) had to use "strong" transverse bearing walls at least for the end walls and the transverse walls next to the end walls. In all cases, special provisions had to be made to provide lateral support to the end walls.

2. The systems with clear spans of 12 ft (3.66 m) or less relied principally on an alternate paths of load support.

3. In short-span systems using an alternate path of load support the following joint reinforcement ties were the most critical: horizontal ties in the vertical joints between adjacent or intersecting bearing walls; continuous vertical ties throughout the building in the same joints; transverse horizontal ties between corridor floor panels and adjoining floor panels; and ties between transverse walls and corridor walls and between transverse walls and corridor floor panels. The alternate mode of load support was also assisted by longitudinal horizontal ties between adjoining floor panels on either side of transverse bearing walls, ties between transverse bearing walls and connecting floor panels, and vertical ties between successive transverse bearing wall panels.

The preceeding conclusions are subject to the following qualifications:

1. The criterion states certain design conditions but does not cover the entire spectrum of possible causes of progressive collapse. For instance; a gas explosion may remove more than the specified number of panels; debris load may cause progressive collapse; or collapse may propagate in the horizontal direction. There is, as yet, no professional consensus as to which cases should be included in, or excluded from, consideration.

2.. Provisions for continuity of joints and miscellaneous ties, similar to those listed in Section 3.4, may eventually be imposed in addition to the rational design conditions required by the criterion. Such prescriptive code provisions could change the characteristics of design solutions.

3. The sample of five systems considered in this report is not very large, and the design solutions do not necessarily represent the only way in which these systems could have complied with the criterion.

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6. References

[1] The Building Research Division Team, Guide Criteria for the Evaluation of Operation Breakthrough Housing Systems, Accession Numbers PB-212055, 212056, 212058, National Technical Information Service (Springfield, Va., December 1970).

[2] Ministry of Housing and Local Government, Report of the Inquiry into the Collapse of Flats at Ronan Point, Canning Town, Her Majesty's Stationary Office (London, U.K., 1968).

[3] Department of Housing and Urban Development, Design and Development of Housing Systems for Operation Breakthrough, U.S. Government Printing Office, (Washington, D.C., 1973).

[4] British Standards Institution, "British Standard Code of Practice for Large Panel Structures, Addendum No. 1 (1970) to CP116, The Structural Use of Precast Concrete (London, U.K., 1970).

1. Hollow-core bearing walls

2. Precast Prestressed Floor Planks

3. Precast Stairwell and Balcony Panels

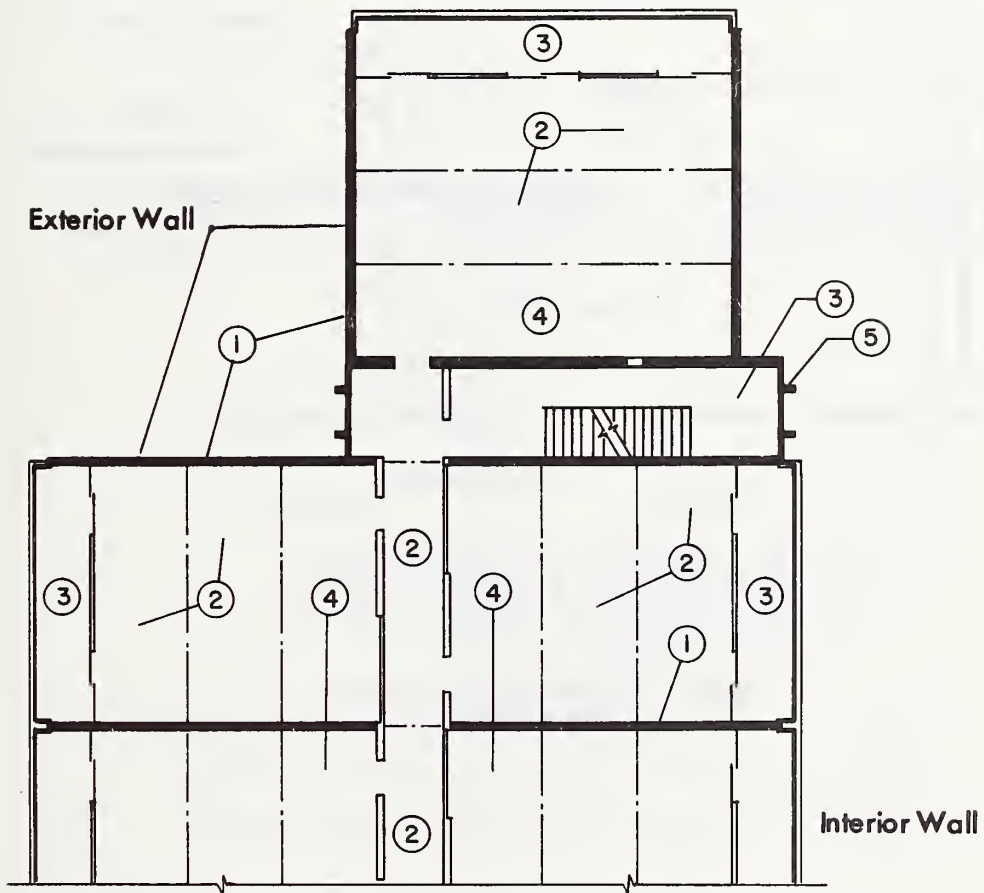4. Heart Modules

5. Double "T" Exterior Panels

Figure 1 Typical Portion of a Floor Plan for the FCE
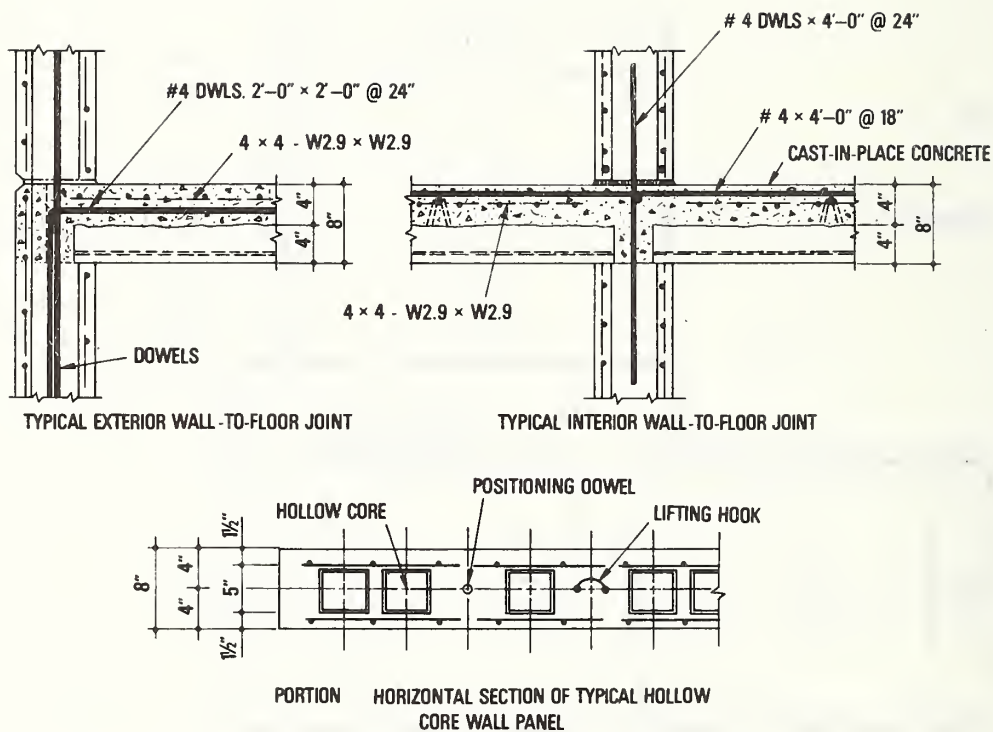Dillon System

#4 DWLS. 2'-0" × 2'-0" @ 24"

4 × 4 - W2.9 × W2.9

4"
4"
8"
4"

DOWELS

TYPICAL EXTERIOR WALL-TO-FLOOR JOINT

4 DWLS × 4'-0" @ 24"

4 × 4'-0" @ 18"

CAST-IN-PLACE CONCRETE

4"
4"
8"
4"

4 × 4 - W2.9 × W2.9

TYPICAL INTERIOR WALL-TO-FLOOR JOINT

1½"
8"
4"
4"
5"
1½"

HOLLOW CORE

POSITIONING DOWEL

LIFTING HOOK

PORTION   HORIZONTAL SECTION OF TYPICAL HOLLOW
CORE WALL PANEL

Figure 2   Typical Hollow Core Wall Panel and
           Floor to Wall Joint Details of FCE -
           Dillon System

CAST IN PLACE
TOPPING

PRECAST
PRESTRESSED
PLANK

1/4" ⌀ ANCHOR BOLT

4 SP 15
16"O.C.

4 B 18
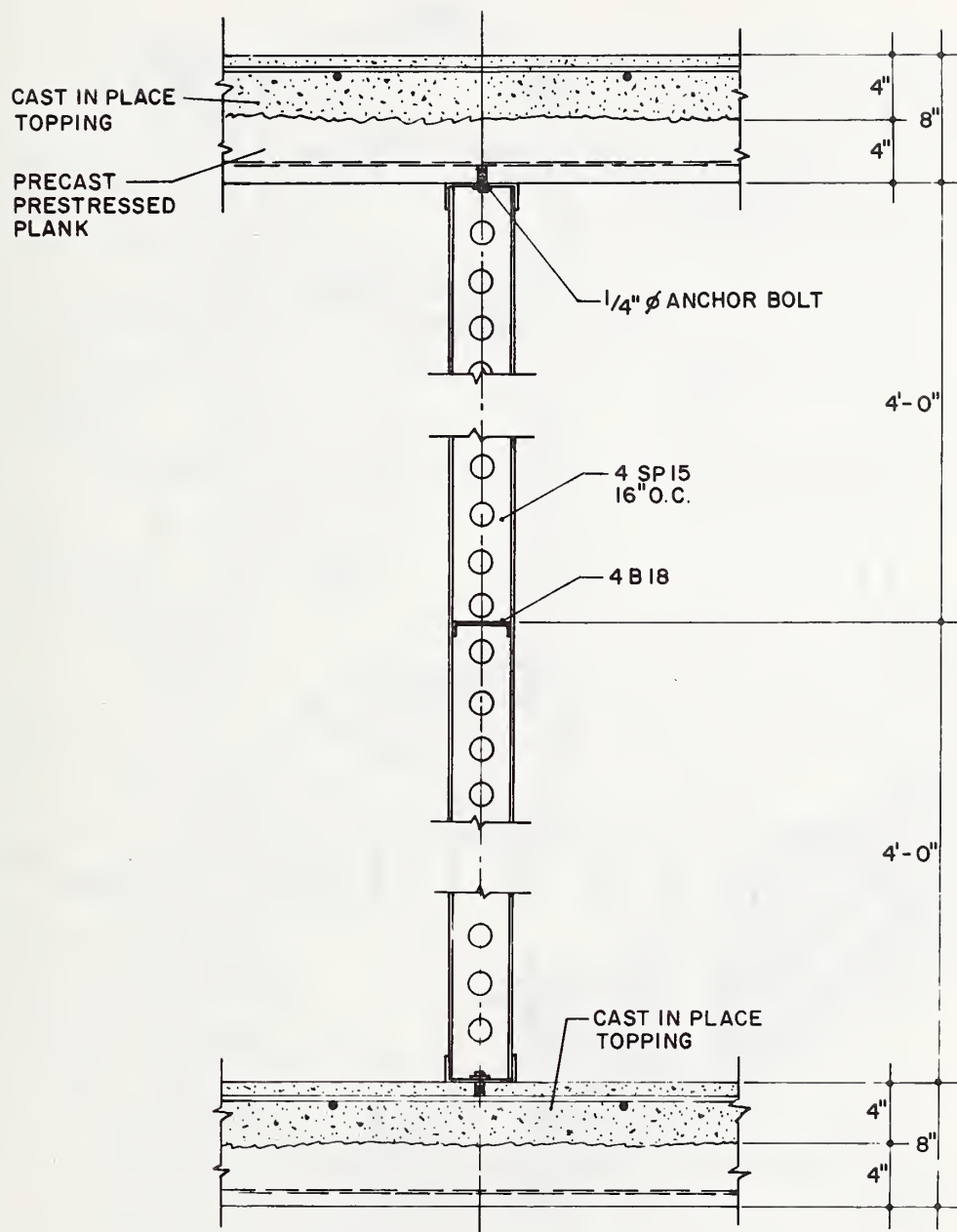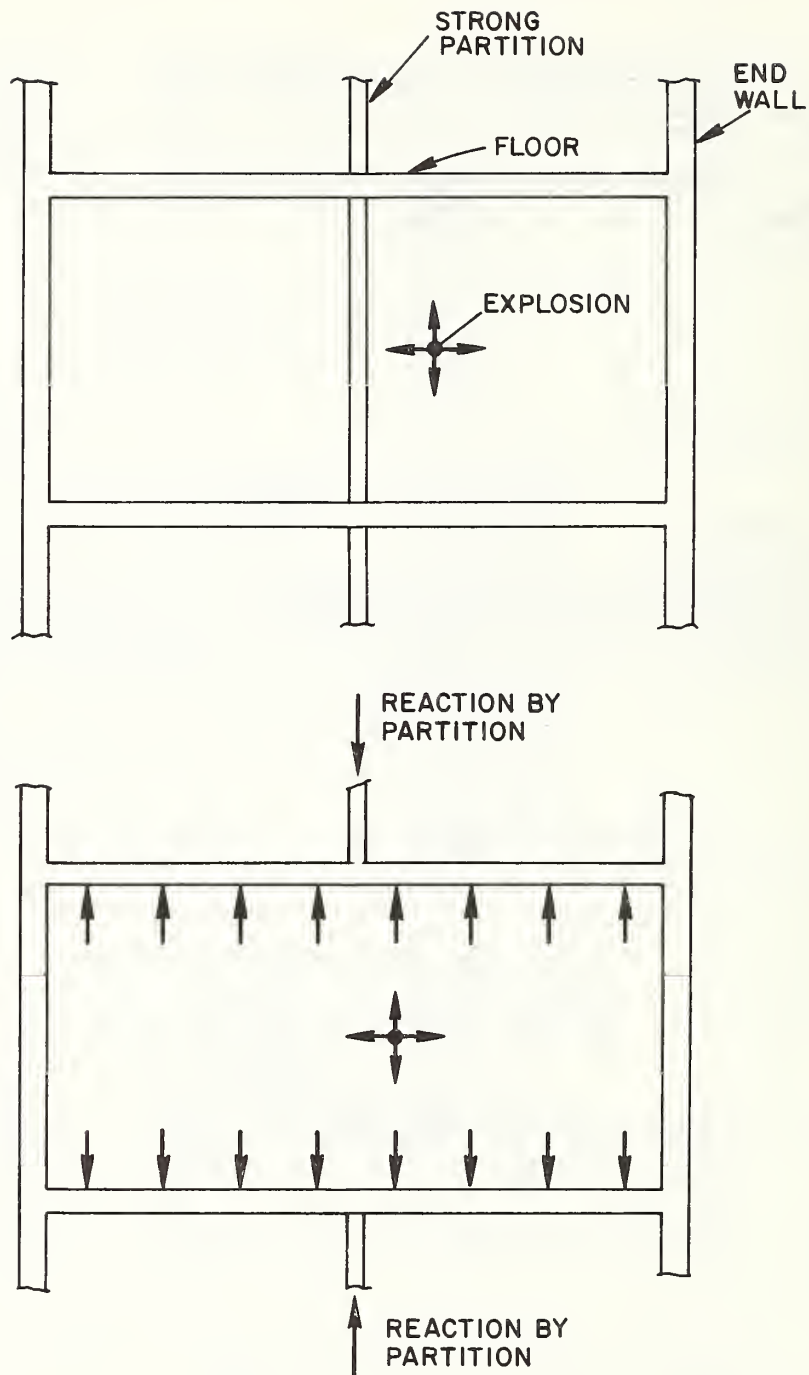
CAST IN PLACE
TOPPING

4"
8"
4"

4'- 0"

4'- 0"

4"
8"
4"

Figure 3 Typical Detail of Specially Designed Partition -
FCE Dillon System

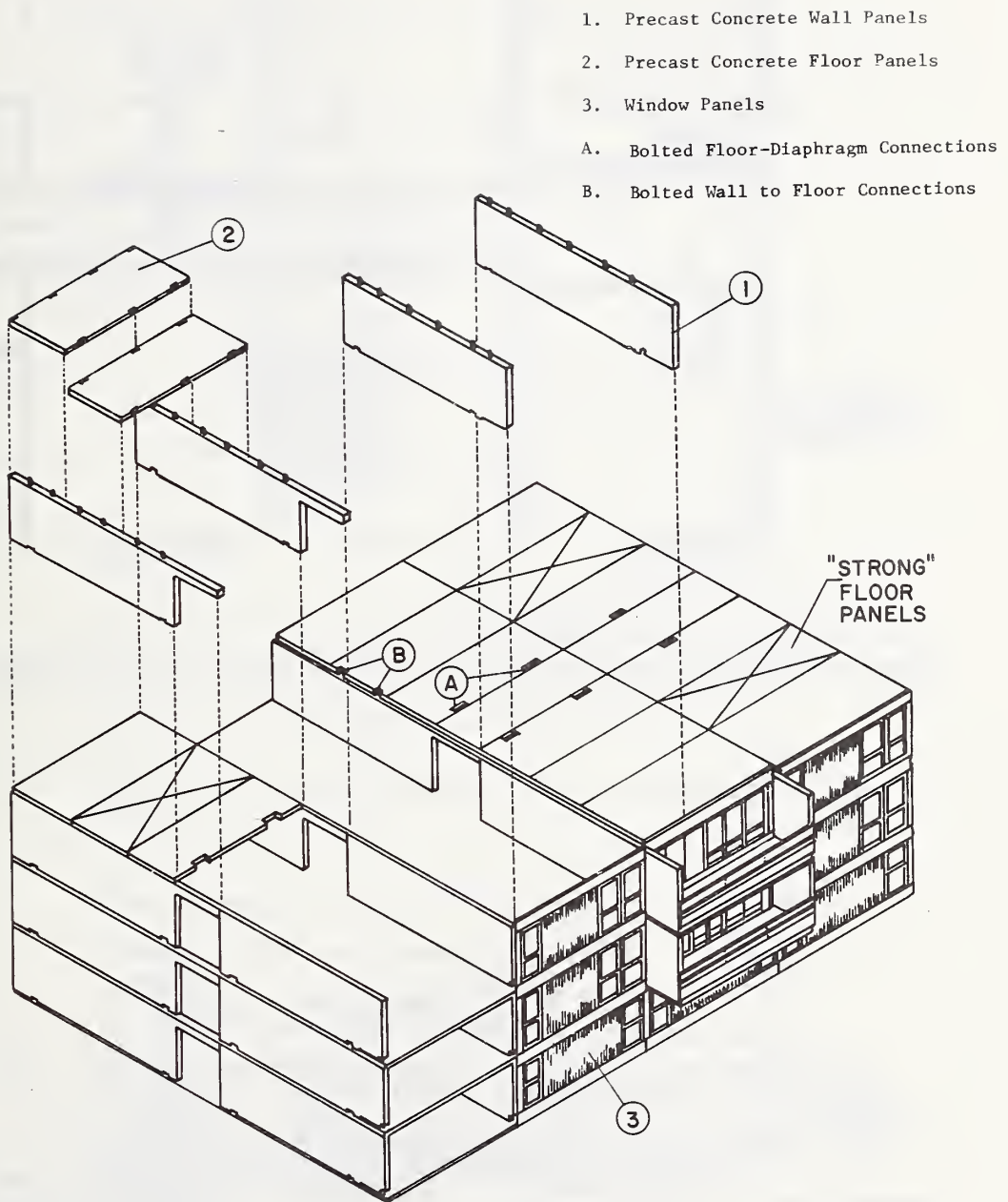Figure 4 Effect of Specially Designed Partition -
FCE Dillon System

1. Precast Concrete Wall Panels
2. Precast Concrete Floor Panels
3. Window Panels
A. Bolted Floor-Diaphragm Connections
B. Bolted Wall to Floor Connections

"STRONG" FLOOR PANELS

Figure 5 Structural Components of the Descon Concordia System

CONNECTION A
FLOOR TO FLOOR

1. FLOOR PANEL
2. EMBEDDED INSERT
3. CONNECTOR PLATE
4. FRICTION BOLTS

Not to scale

1. BEARING WALL PANEL
2. FLOOR PANEL
3. WALL INSERT - TOP
4. WALL INSERT - BOTTOM
5. METAL SHIMS
6. FLOOR INSERT
7. CONNECTION MAKE-UP PIECES
8. FRICTION BOLTS

CONNECTION B
WALL TO FLOOR
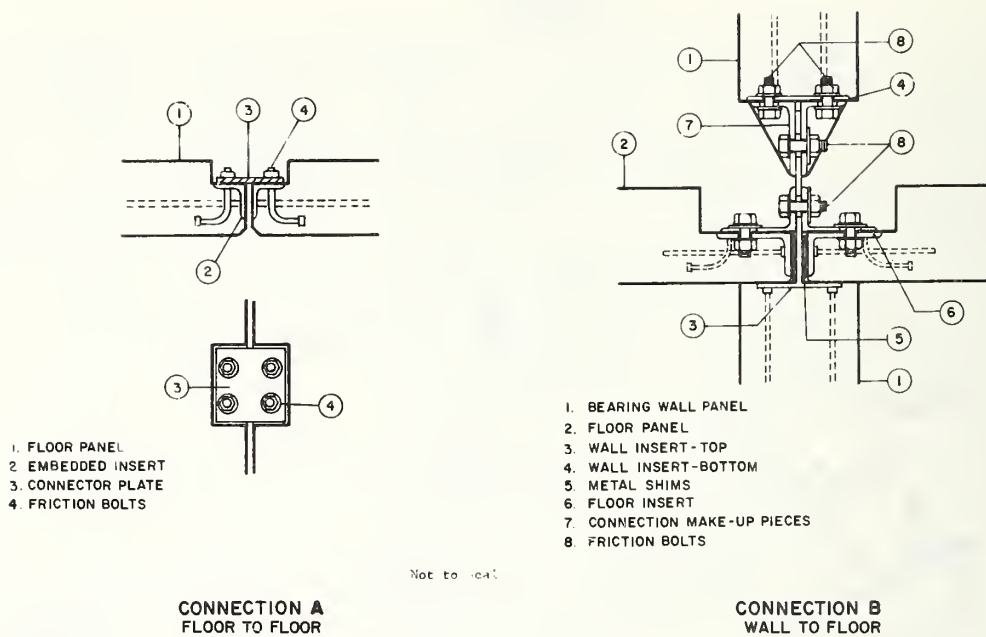
Figure 6   Typical Panel Connections for Descon Concordia System

5' – 4"

2' – 8"   2' – 8"

9"   9"

Reinforced Band   6"7 Tap

6 1/2" 5 1/4"

Prestressing Stand   4"7 Bat.   #4 @ 24" O.C.   ₵ Floor Panel

₵ of Reinforced Band
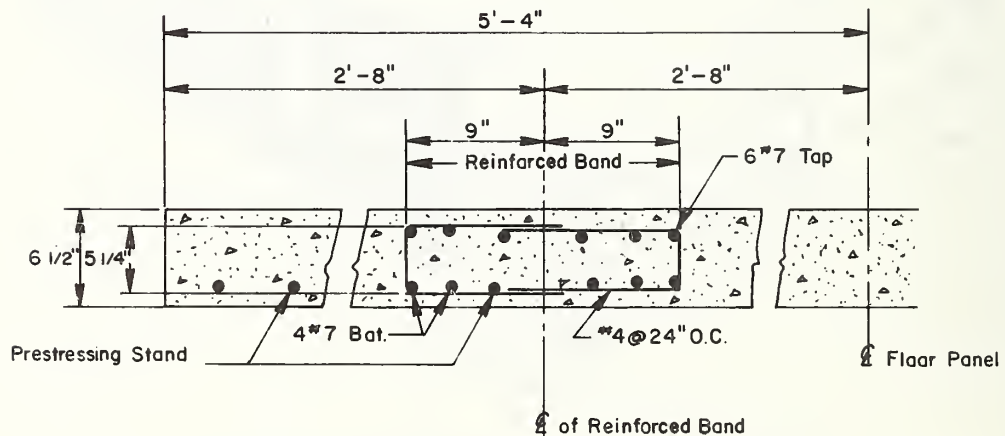
Figure 7   Section Through Strong Floor Panel of Descon
           Concordia System

1. Strong Bearing Wall Panela   5. Floor Panels
2. Interior Bearing Wall-Panels   6. Strong Floor Panels
3. Exterior Wall Panels   7. Corridor Floor Panels
4. Corridor Wall Panels
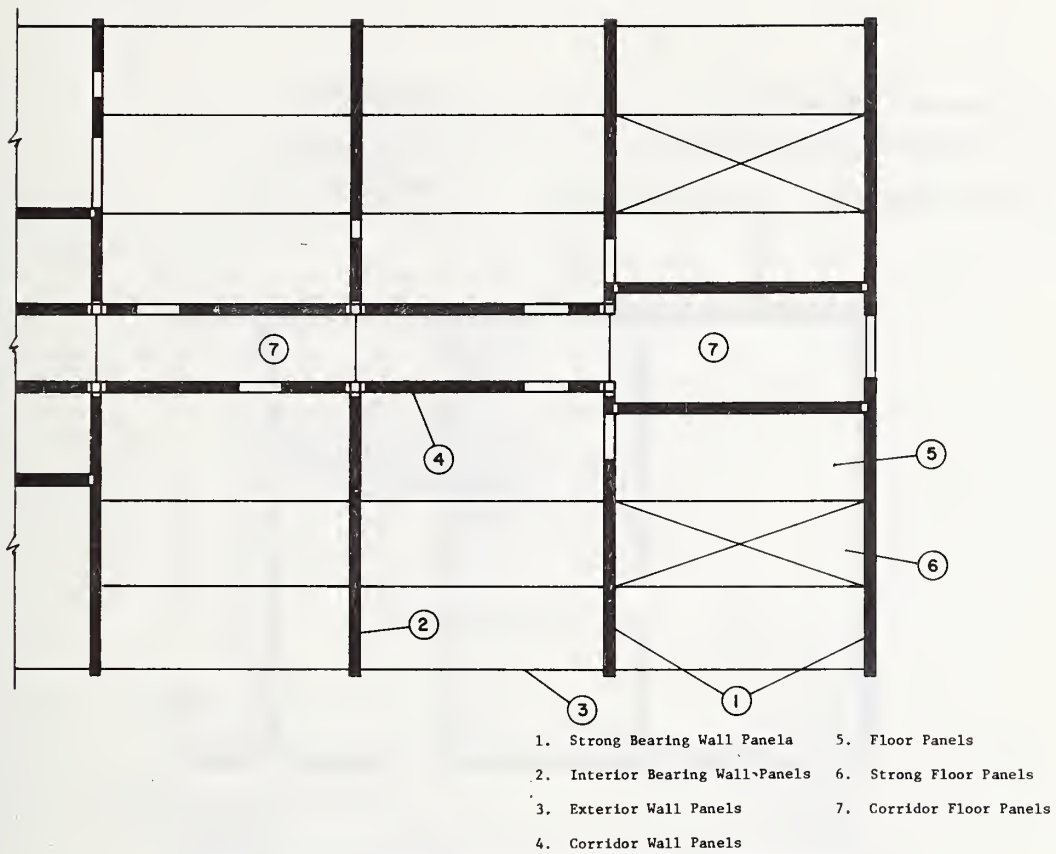
Figure 8   Portion of Floor Plan of Rouse-Wates System

1. Floor Panel

2. Cast in Place Concrete Joint

3. Transverse Joint Reinforcement

4. Longitudinal Joint Reinforcement

5. Lifting/Leveling Bolt

6. Leveling Cone

7. Precast Concrete Wall

8. Grout Bed
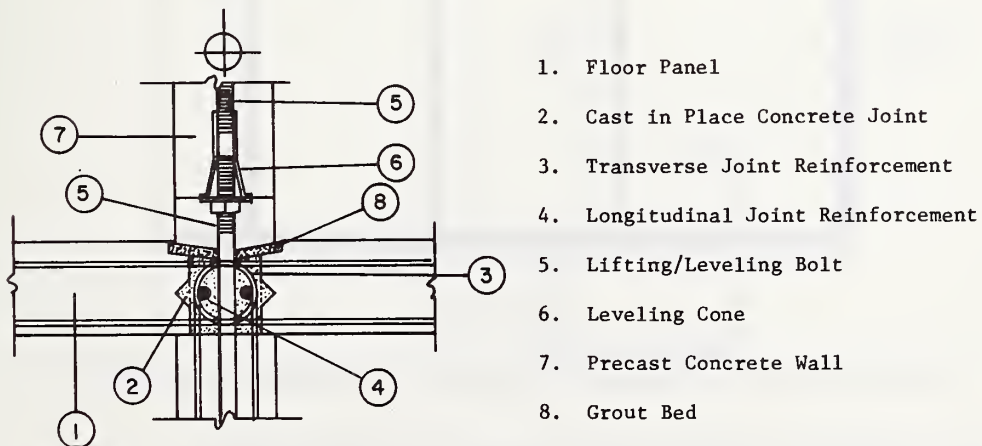
*Figure 9   Typical Cast-in-Place Horizontal
Joint of Rouse Wates System*

1. Transverse End Wall Panel
2. Transverse Interior Wall Panel
3. Corridor Wall Panel

4. Facade Panels
5. Floor Panels
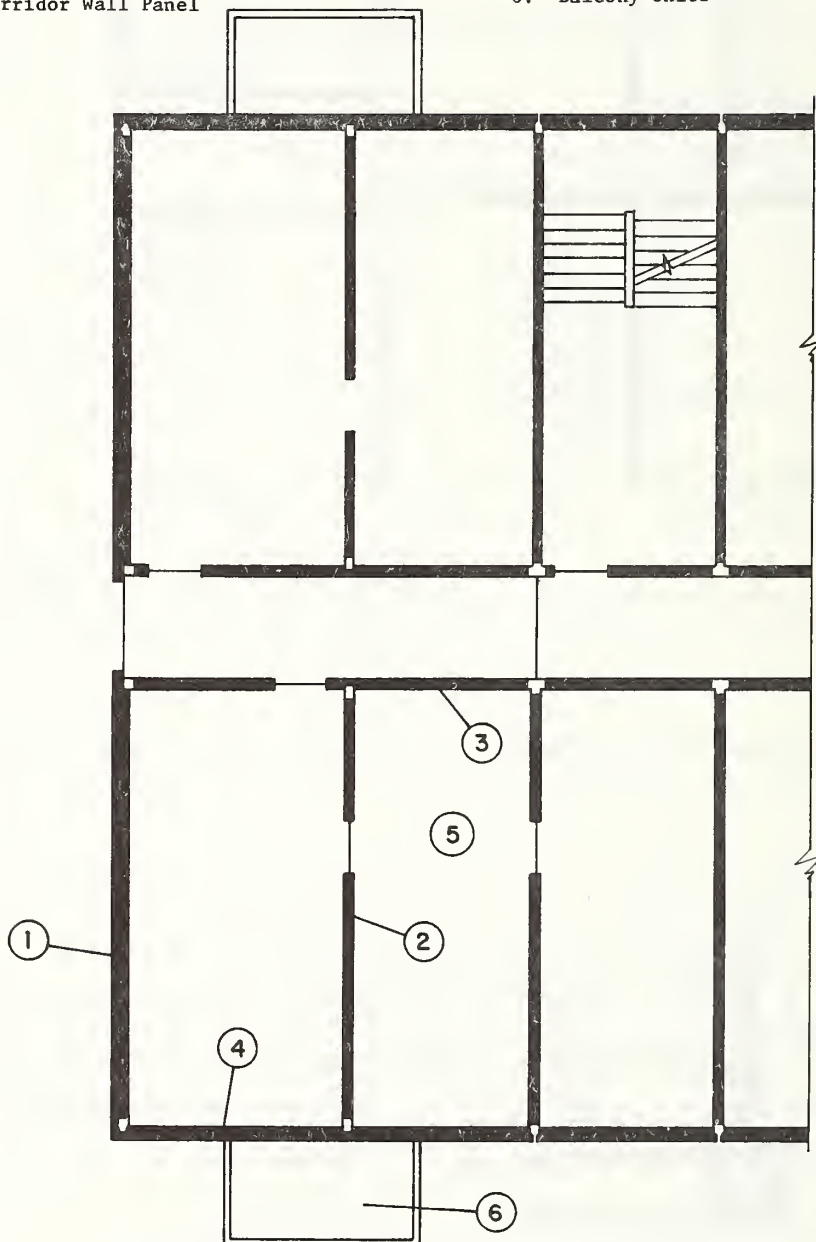6. Balcony Units

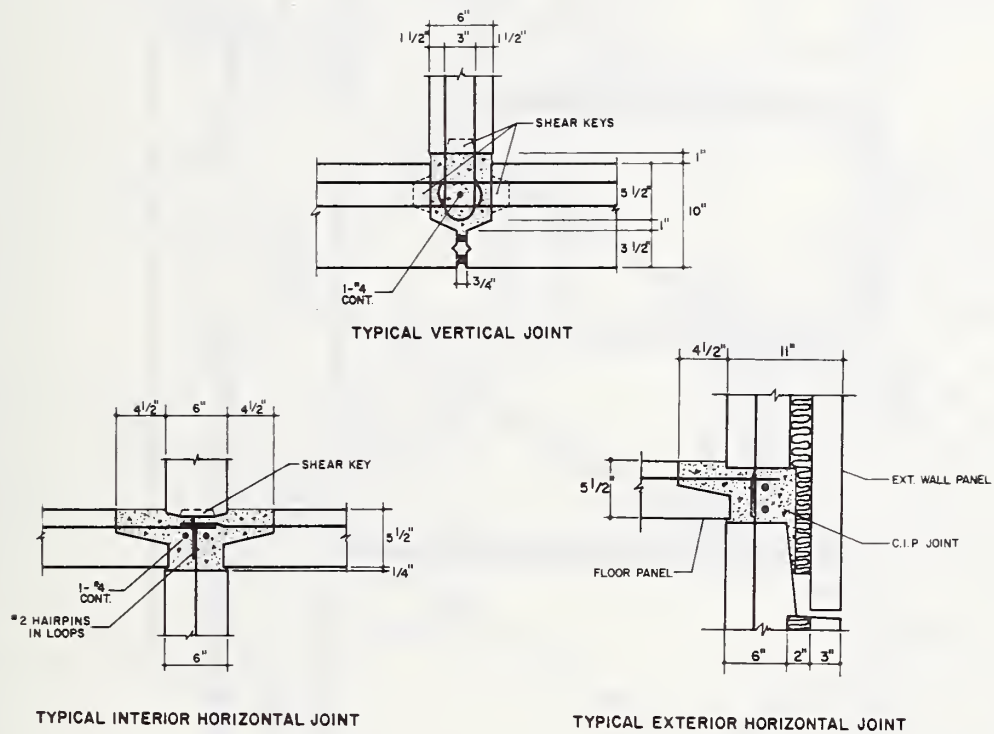*Figure 10   Portion of Typical Floor Plan of Camci System*

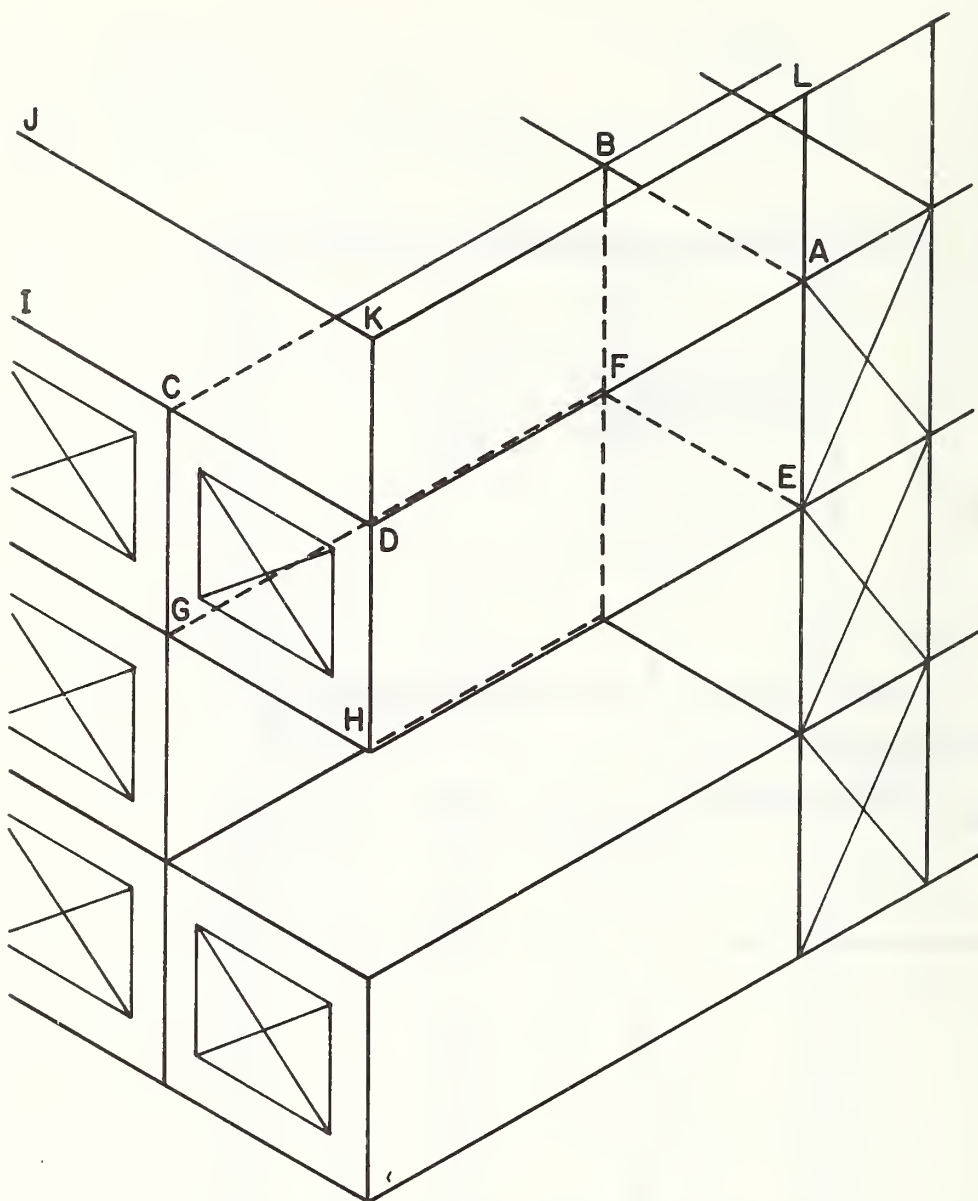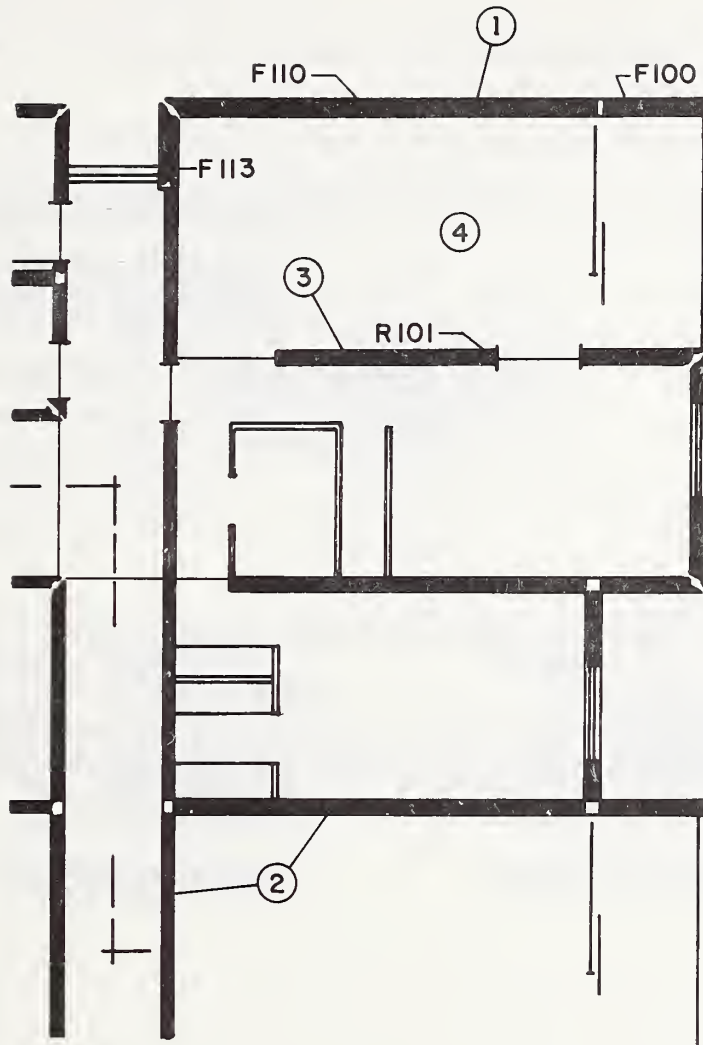Figure 11   Typical Connection Details of Camci System

Figure 12 Camci System - Critical Condition for Progressive Collapse

1. Exterior Wall Panels

2. Interior Wall Panels

3. Strong Interior Wall Panels

4. Floor Panels

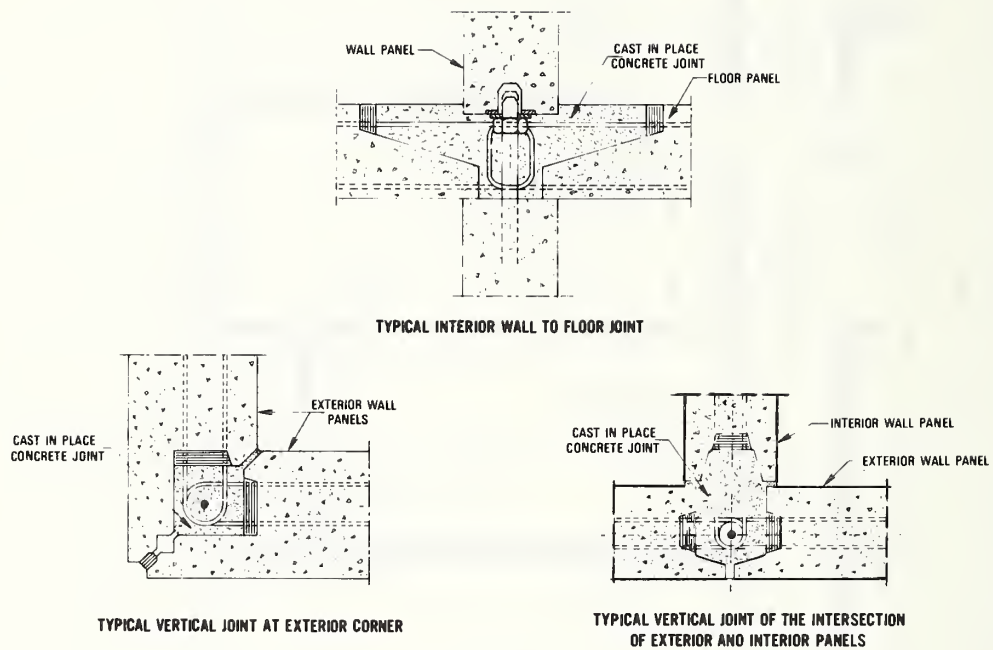*Figure 13 Portion of a Typical Floor Plan of the BSI System*

WALL PANEL

CAST IN PLACE
CONCRETE JOINT

FLOOR PANEL

TYPICAL INTERIOR WALL TO FLOOR JOINT

EXTERIOR WALL
PANELS

CAST IN PLACE
CONCRETE JOINT

TYPICAL VERTICAL JOINT AT EXTERIOR CORNER

CAST IN PLACE
CONCRETE JOINT

INTERIOR WALL PANEL

EXTERIOR WALL PANEL

**TYPICAL VERTICAL JOINT OF THE INTERSECTION
OF EXTERIOR AND INTERIOR PANELS**

Figure 14   Typical Joint Details for BSI System

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16. ABSTRACT *(A 200-word or less factual summary of most significant information. If document includes a significant bibliography or literature survey, mention it here.)*

The design solutions used by five U.S. precast concrete housing systems to comply with a provision against progressive collapse are studied and compared. Some common characteristics of the design solutions are identified.

17. KEY WORDS *(six to twelve entries; alphabetical order; capitalize only the first letter of the first key word unless a proper name; separated by semicolons)*

Building systems; housing systems; large-panel structures; precast concrete construction; progressive collapse; structural design; structural joints.

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